Best Available Technology Report for the Aggregate and Concrete Industries in Europe

Best available concepts and guidelines

ECO-SERVE Network, Cluster 3:
Aggregate and Concrete Production

November 2006

Rev. B

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SUMMARY AND CONCLUSIONS

This BAT-report includes information about optimisation of aggregate production as well gate and concrete production and future research needs in these sectors.

The aggregate and concrete industry is facing a growing, public awareness relating to the environmental profile of its activities. With concrete being the by far most important construction material and annual aggregate production being of the order of 10 tonnes per capita throughout Europe therewith being a major part of the environmental impact. The objective of Cluster 3 has therefore been to contribute to a reduction of environmental impact for aggregates and concrete production.

Best Available Technology (BAT) denotes a possible technical solution to solve a sustainability problem. BAT may be commonly used in the industry and therefore serve as baseline at the same time, or it may be state-of-the-art technology implemented only in a few production facilities. Furthermore, BAT must be available, i.e. it should be a technology that has been proved applicable in a practical production scale.

BAT is not an absolute measure. “Best Available Technology” should always be seen in a context with local conditions since it depends strongly on the local conditions ruling at the location of the production plant. Therefore, it is not possible to agree on a single European BAT since it is bound to vary from country to country – and even from region to region within a single country. For instance a technology that is considered BAT in one location may very well be second-BAT in another location due to the local conditions. This should be kept in mind when discussing sustainability issues across Europe. In some cases it may be more plausible to consider a family of BAT’s or a Best Available Concept (“BAC”) instead of a single technology.

Aggregates

The aggregate part discusses sustainability in the aggregate production industry in relation to mineral resources. It is concluded that natural sand and gravel resources are being depleted in Europe and the trend is towards using more of crushed and manufactured aggregates as well as recycled material. Conflicts due to land use for quarrying are common all over Europe and the need for long term planning is a pressing social, economical and political issue. The importance of mass balance and need to reduce surplus materials is emphasised and the focus should be on no-waste production in the aggregate industry. The energy consumption for aggregate production is relatively small, compared to the energy consumption for the production of concrete, but the transport of aggregates from quarry to customer has large energy impact and is increasing in general in Europe.

The issues and challenges for the Aggregate Industry, as identified in the Baseline Report, suggest that the BAT term most appropriately be understood as a Best Available Concept (“BAC”) – including environmental and sustainability aspects along the entire process line from materials inventory, via production and use, to final area reclamation.
More than most industries, the aggregate industry will be strongly dependant on local conditions relating first of all to geological conditions and resource availability. Therefore the preparation of a BAT (“BAC”) will have to take into consideration the different

situations prevailing in different parts of Europe, ending up with a set of best concepts for key areas, within which specific BATs may be developed based on the characteristic, local conditions in order to meet the Eco-Serve objectives.

Reducing the adverse environmental impact of the pavement and concrete construction industry on the external environment, improving the working environment within this industry, ensuring European growth and wealth by increasing the productivity and competitiveness of the raw materials, production and the construction industry as well as enhancing the quality, durability and service life of pavements and concrete structures through sustainable developments.

Somewhat simplified, the activities of the aggregate industry can be compiled into *four essential phases*:

1. Inventory and planning
2. Quarrying and production
3. Use of aggregates in construction
4. Reclamation of mined-out area

Each of these phases will contain a number of sub-activities. Within each essential phase there will also be a set of environmental challenges and sustainability issues to be handled. Elements of BAT will have to be identified for each of these within the overall concept – to reduce environmental impact and to improve sustainability.

Aggregates can only be extracted where nature has placed them. Thus, the local geological setting is the first and most essential condition for locating a quarry. This means that quarries may have to be located in the countryside where constraints against any form of development are intense. Alternatively quarries will have to be located in densely populated or industrialized areas where constraints against dust, noise, vibration and truck traffic are not less intense. The final alternative for the consumer/society may have to be import of aggregates from more remote sources, which involves heavy traffic load over long distances and at the same time the above mentioned constraints at the locations of production.

Once operative, the quarrying process incorporates a series of sub-activities to be considered also from an environmental point of view. *The mass balance* will often be the key issue of sustainability in quarry production: A total mass balance should be aimed at, avoiding surplus materials like fines or over-size to be left in waste deposits. The probably largest energy consumption within the aggregate industry is that related to transport Aggregates are crucial ingredients in most construction activities and construction materials, the primary volumes being in road pavements, road bases and concrete. These are also the down-stream materials where the strictest requirements are set to properties and quality. Sub-activities in aggregate use will be performance analyses, quality control and materials.

A sustainable use of aggregates can be said to be a use that saves resources and minimizes waste deposits, and which also provides an end product with a minimum of energy consumption and a maximum of added value. Some of the ways this can be done is to substitute natural aggregate with recycled aggregates or replace sand/gravel with available crushed materials. Too strict and narrow requirements should be avioded e.g. road materials in order to have a broader utilisation of sizes and less surplus materials.

Key actions concerning reclamation of quarried areas are becoming still more vital in order to obtain the necessary permits for quarrying. This is an issue which will strongly depend on local conditions, needs and political priorities.

The problems with waste depositing from construction and demolition activities and the need for alternative mineral resources for new construction have been the two main drivers for research activities into recycled and alternative aggregates for some years

Concrete

The production of concrete annually amounts to 1.5-3 tonne per capita in the industrialized world: this makes the concrete industry including all of its suppliers a major player in the building sector. Thus, improving the sustainability of the concrete industry automatically will lead to significant improvements in the building sector as a whole.
The aggregate part of concrete normally accounts for 70-75 % of its volume and therefore the environmental issues of aggregate production strongly influence concrete production. Furthermore, cement production is associated with large energy consumption and CO_2 emissions. Thus, the sustainability of concrete as a material is strongly influenced by the cement industry and the aggregate industry.

The concrete industry has been handling sustainability issues throughout the last two decades. The development of sustainable concrete production has almost always been driven by economical reasons but it is expected that in the future environmental design will be treated alongside conventional design aspects such as safety, reliability and durability as it is introduced in a recent fib Bulletin. Therefore, a broad description of BAT will serve as a tool to distribute technologies between European countries and widen the awareness of sustainable production methods.

Furthermore, a BAT may be subdivided into sub-technologies. For instance self-compacting concrete is considered a BAT on its own but the individual technologies enabling production of SCC may be considered as individually BAT’s.

It is generally recognised that concrete production is a complex topic when it comes to sustainability issues, partly because various constituents/materials are involved and partly because sustainable concrete production may be defined in many ways. One of the main benefits of concrete is the fact that it is accessible world-wide. The main constituents for concrete are available all around the globe as well as the production technologies. However, the concrete compositions all around Europe are different. They depend by materials locally available, regulations and most, tradition. Thus, concrete is very much a local material for local applications. Therefore, concrete is basically an environmentally-friendly material if it is produced from locally available constituents and if furthermore, it is produced to fit its purpose.

Since the local conditions are of great importance it is not attempted in this report to rank the BAT’s. Instead they should be considered a catalogue of ideas for inspiration and hopefully help to increase the level of the whole European concrete industry. Furthermore, it is recognised that BAT for sustainable concrete production is a very dynamic concept. Especially when it comes to production control, the development of systems for monitoring and supervising the production of concrete is improving rapidly, right from its constituent materials to the performance of the finished concrete product.

The BAT's regarding concrete can be grouped in the following categories:

1. Optimisation of mix design with respect to clinker content
2. Production methods
3. Self-Compacting Concrete

Since one of the main environmental issues associated with concrete production is CO2-emissions and the greenhouse effect, the amount of Portland clinker is of paramount importance of the environmental performance of concrete. The broad picture of sustainable concrete production is that item 1 above is being implemented all around Europe, which is mainly a result both of the cement industry being forced to improve their environmental profile and possibly reduce their production costs. Furthermore, there are economical benefits by reducing the cement content in concrete. The reduction of cement content can be done in two ways. Either at the cement plant by the cement producer obtaining blended cements or at the concrete plant where pure Portland cement is mixed with fly ash, silica fume, slag, etc. in the concrete mixer by the concrete manufacturer. The change from pure Portland cement to blended cement is clearly reflected in the cement production figures.

Every concrete manufacturer is of course optimizing his concrete mix design with respect to cement content since this is typically the expensive constituent. Therefore, an economical optimisation of concrete mix design very often also results in a sustainable one.
The implementation of SCC is another issue that is expected to be increasing significantly across Europe. There are still some technical problems that need to be solved before it can be accepted as a well-proven technology.

SCC has a long line of advantages as it was described in the Baseline Report. From the contractors point of view costly labour operations are avoided improving the efficiency of the building site. Furthermore, the concrete workers avoid poker vibration which is a huge benefit for their working environment. When vibration is omitted from casting operations the workers experience a less strenuous work with significantly less noise and vibration exposure.

It should also be noted that SCC is believed to increase the durability relatively to vibrated concrete. This is due to the lack of damage to the internal structure, which is normally associated with vibration.

Conclusion

Much can be accomplished by using the available technology to a greater extent already today.

Performance based requirements would be beneficiary to the development or use of better methods than today.

CONTENTS

1 INTRODUCTION

This BAT report is the second deliverable (3.1.2) of Cluster 3 “Aggregate and Concrete Production” of the ECO-SERVE Network. It relates to subtask 3.3 according to the Work Plan dated February, 2002 and is also the result from Milestones 4, 5 and 6.

The BAT-report is written by the following working group appointed by the principal contractors of Cluster 3 (Table 1.1):

- Fredrik Gränne, cluster co-ordinator, NCC, Sweden
- Svein Willy Danielsen, Franzefoss Pukk, Norway
- Gudni Jonsson, IBRI, Iceland
- Guido Krage, IBRI, Iceland
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However, the input and comments received from cluster members are greatly acknowledged.

Following the introduction, two chapters (nos. 2, and 3) are devoted to sustainability issues concerning aggregate and concrete production, and recycling. Finally, the BAT-report contains recommendations for further research in Chapter 4 and finally a list of references in Chapter 5.

1.1 Background and scope

The ECO-SERVE Network is financed from the European Commission under the 5th Framework Program. Reference is made to www.eco-serve.net where the Baseline Report dated June 2004 is available for download. The present BAT Report should not be read without having the Baseline Report available since not all of the definitions and limitations given in the Baseline Report are repeated herein.

Cluster 3 ”Concrete and Aggregate production” is a one out of four cluster within the network. The other clusters deal with wastes as secondary fuels and raw materials for cement production, production and application of blended cements, and pavement production and design, respectively (Figure 1.1). Furthermore, ECO-SERVE contains an activity named Task 2 crossing over the clusters in its effort to describe and formulate environmental indicators. Reference is made to the reports produced by the clusters and Task 2.

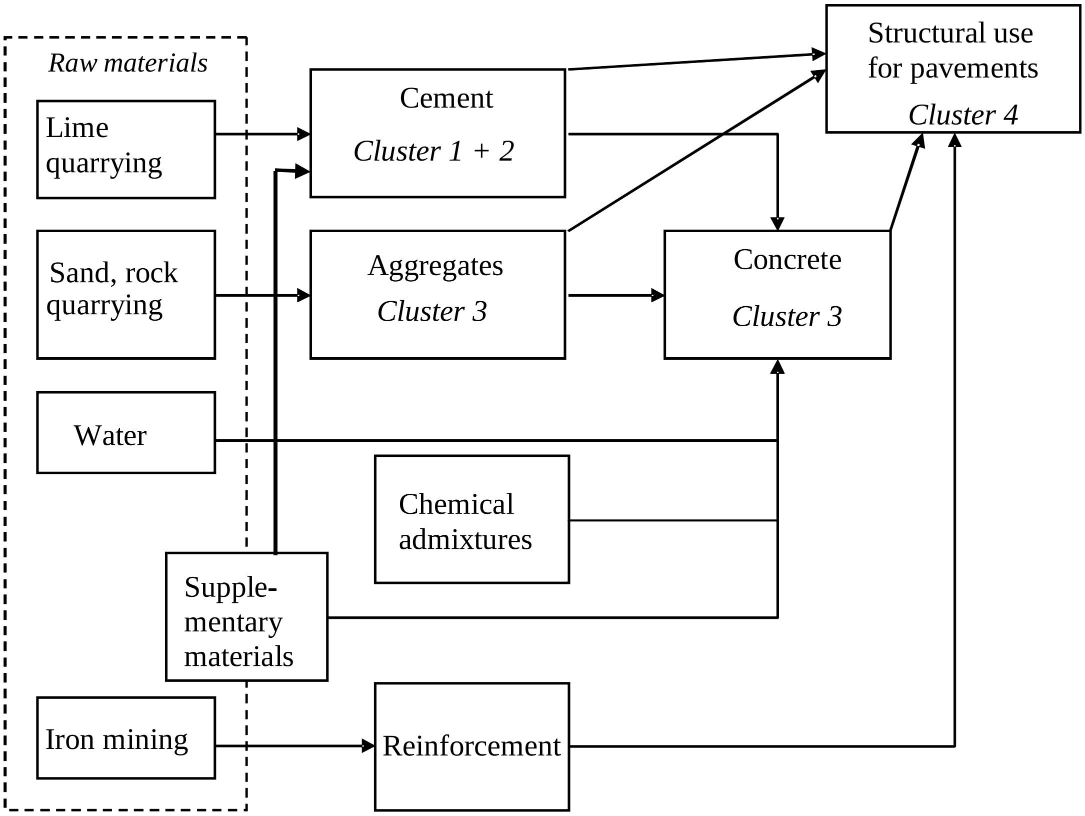

Figure 1.1 Constituents of concrete and its relationship with the ECO-SERVE Network clusters. Pozzolanas may be natural volcanic material or waste products from power plants.

Due to practical considerations in order to keep the ECO-SERVE project within plausible limits of time and funding, Cluster 3 is limited to deal with the production of aggregates and concrete (Figure 1.1). Thus, we are mainly considering environmental topics related to the production of concrete and aggregates and not necessarily the full life-cycle of a structure (e.g. a building or a road structure). The implications of this choice are discussed further under the various sections of the report.

According to the ECO-SERVE network work plan for Cluster 3 dated February, 2002, the overall objective of Cluster 3 is to contribute to a reduction of the environmental impact of aggregate and concrete production making them more cost-effective, while improving or at least maintaining their required technical performance.

In our effort to reach this ambitious objective an overview of current practises and ongoing research activities in the field of sustainable aggregate and concrete production has been gathered in the Baseline Report[1].

1.2 What is Best Available Technology?

Best Available Technology (BAT) denotes a possible (technical) solution to solve/mitigate a sustainability problem. BAT may be commonly used in the industry and therefore serve as baseline at the same time, or it may be state-of-the-art technology implemented only in a few production facilities. Furthermore, BAT must be available, i.e. it should be a technology that has been proved applicable in a practical production scale.

Furthermore, a BAT may be subdivided into sub-technologies. For instance self-compacting concrete is considered a BAT on its own but the individual technologies enabling production of SCC may considered be considered as individually BAT's.

BAT is not an absolute measure. It depends strongly on the local conditions ruling at the location of the production plant:

- Normal procedures and experiences in the building industry.
- Availability of materials and their costs (both raw and processed).
- Visibility of sustainability issues on the public agenda. Are the building owners willing to pay for sustainability?
- Population density (land-use, availability of natural resources).
- Energy and labour costs.
- Legislation, standardisation and taxes.
- Transportation costs.

Therefore, it is not possible to agree on a single European BAT since it is bound to vary from country to country – and even from region to region within a single country. For instance a technology that is considered BAT in one location may very well be second-BAT in another location due to the local conditions. This should be kept in mind when discussing sustainability issues across Europe.

In some cases it may be more plausible to consider a family of BAT's or a best available concept instead of a single technology.

Another way to act sustainable is of course to use less quantities of material, which means that sustainability can be a task for the structural design engineers as well but that is not the focus in this report.

2 AGGREGATE PRODUCTION

2.1 Introduction

The issues and challenges for the Aggregate Industry, as identified in the Baseline report, suggest that the BAT term most appropriately be understood as a ***Best Available Concept (“BAC”)*** – including environmental and sustainability aspects along the entire process line from materials inventory, via production and use, to final area reclamation.

More than most industries, the aggregate industry will be strongly dependant on local conditions relating first of all to geological conditions and resource availability. Therefore the preparation of a BAT (“*BAC”*) will have to take into consideration the different situations prevailing in different parts of Europe, ending up with a set of *best concepts* for key areas, within which specific BATs may be developed based on the characteristic, local conditions in order to meet the Eco-Serve objectives of:

- “Reducing the adverse environmental impact of the pavement and concrete construction industry on the external environment,
- Improving the working environment within this industry,
- Ensuring European growth and wealth by increasing the productivity and competitiveness of the raw materials, production and the construction industry as well as enhancing the quality, durability and service life of pavements and concrete structures through sustainable developments.”

Note as to local, geological conditions that it may sometimes be relevant to consider typicality more than country when choosing a best available technology in a specific place of use. Most countries offer geological differences (hard rock, weak rock, different rock types, sand/gravel sediments etc). Though some characteristic, regional differences do exist and must be taken into consideration:

- Sand/gravel resources in the previously glaciated areas in the northern and alpine countries are primarily of glaciofluvial origin, opposite to the situation in central European countries where sand/gravel is mainly due to the activities of the great rivers. And in some coastal North Sea regions sea dredged materials are most common. These three kinds of sediments are fundamentally different in their composition and also in their engineering properties.
- The large mountain ranges have provided some countries with an abundance of hard rock of many kinds, while a few countries like Denmark and Holland are totally dependant of importing such materials.
- Different relative distribution of sand/gravel and hard rock respectively have also resulted in the development of highly different application technology for aggregates in the concrete industry, where e.g. Spain can show a long term experience with 100% crushed limestone aggregates, Norway and Sweden are developing crushed aggregate concrete with rock types a little more difficult for this purpose, and the sand rich regions have hardly needed such experience at all.
- When it comes to the production and use of recycled materials there is a similar, characteristic difference, but now mainly between densely and scarcely populated countries – depending on availability of natural resources, access to waste deposition areas, and the volume of structures being demolished. Clearly there is a great

difference in local Best Practice between those who specify a recycled content in concrete (e.g. Holland), those who prohibit it (e.g. Denmark) and those who intend to use when the current situation makes it favourable.
- And finally, BAT in getting access to, opening and reclaiming a quarry will to a great extent depend on factors like population density, supply options and the local/regional need for materials – and thus differ a lot throughout Europe.

Somewhat simplified, the activities of the aggregate industry can be compiled into **four essential phases:**

1. Inventory and planning
2. Quarrying and production
3. Use of aggregates in construction
4. Reclamation of mined-out area.

Each of these phases will contain a number of sub-activities. Within each essential phase there will also be a set of environmental challenges and sustainability issues to be handled. Elements of BAT will have to be identified for each of these within the overall concept – to reduce environmental impact and to improve sustainability.

These being the phases related to the production and use of primary aggregates, there is also an increasing need to look into the need for options in **replacing parts of the primary aggregates with artificial and/or secondary aggregates.** This could be all from crushed and sorted C&D waste from e.g. recycling, to aggregates originating from more advanced production processes – e.g. thermal ones. An increased use of such materials is an environmental issue by contributing to reduced waste depositing, as well as an issue of sustainability by reducing the consumption of scarce natural resources.

This is a large and complex topic, which is also very much depending on the local situation at the place of production and use; population density, building tradition and predominant building materials, availability of primary materials, transport logistics and the age and standard of the existing building stock.

2.2 Phase 1 Inventory and planning

2.2.1 Sub-activities

During the initial stage of resource inventory and quarry planning, several issues need to be considered and objectives need to be met as a basis for the future quarrying activities:
- *Geological mapping* – investigation of potential resources will be the first step in order to evaluate options and problems relating to e.g. volume and complexity of the resources, materials properties and the logistic aspects of assessing the area and transporting the products.
- *Regulatory issues* need to be handled seriously as the pre-requisite to get access to the resources, focusing on potential land use and neighbourhood conflicts, biodiversity of the area, pollution issues, transport planning and archaeological and geological heritage.

- *Planning of the future exploration and quarrying* must be undertaken, incorporating excavation and production planning, investments and finance, equipment and production lay-out, the choice of methods to meet materials requirements, and finally the commissioning of the plant.
- *Planning of the future land reclamation* will often be needed prior to obtaining a quarrying permit. Parts of this planning may be the final shaping of landscapes, presentation of alternative and sustainable land use – e.g. residential or recreational areas, how to protect the environment – including biodiversity, and finally alternatives for industrial use.

2.2.2 Key environmental issues

The local and geological conditions will be determinant for all quarrying and access to recourses.

Aggregates can only be extracted where nature has placed them. Thus, the local geological setting is the first and most essential condition for locating a quarry. This means that quarries may have to be located in the countryside where constraints against any form of development are intense. Alternatively quarries will have to be located in densely populated or industrialized areas where constraints against dust, noise, vibration and truck traffic are not less intense.

The final alternative for the consumer/society may have to be import of aggregates from more remote sources, which involves heavy traffic load over long distances and at the same time the above mentioned constraints at the locations of production.

2.2.3 Issues of sustainability

Resource management is the key element of sustainability for aggregate production. Today the primary challenge for the industry is the access to geological recourses, the exploitation of which is a pre-condition for keeping up a modern society. The world-wide need for and consumption of aggregates of approx 10 tons per capita represents a great challenge to society when it comes to balance the long term access to and priority of resources against all other needs for land-use and environmental protection.

In order to be sustainable, any encroach upon nature should be justified by increased values for the society, both relating to the products made and to the area left for later use. All planning should be based on due knowledge of geology and all other relevant nature values relating to the area.

The issue of replacing an increasing amount of virgin aggregates with recycled materials from C&D waste has been focused on being a means of increasing sustainability. This is an option within limitations, since the current supply of C&D waste from production as well as demolition will allow for a maximum of approx 10% replacement as an average. And due to logistics and geographic differences, the practical amount will probably be closer to 5%.

2.2.4 Elements of BAT

In order to meet the objectives above, the inventory and planning phase should include:

- *Identify resources*: Identify aggregate resources that can meet society's demand in the relevant area – consider alternatives relating to materials quality, availability, economic feasibility. This applies first of all to geological resources, but should also involve alternative, e.g. recycled materials.
- *Identify potential conflicts*: Provide sound, unbiased scientific information to the permitting process to allow better-informed decision-making.
- *Provide vital information for planning* for the availability of aggregate sources: Identify potential environmental problems and suggest solutions to solve them – or scientific basis for decision-making. The balance and choice between local quarries providing aggregates within short transport distance and large regional quarries that save local area but need more transport should be considered.
- *Identify future options as to reclamation* or secondary industrial use, in order to increase the long-term value of the area.
- *Identify specific means for reducing the environmental impact*, relating to pollution and noise control, materials handling and transport, safeguarding biodiversity, avoiding surplus deposits, forming the quarry for later land restoration.
- *Locate the quarry* in a way as to avoid visibility and earn acceptance from the neighbourhood.

The BAT actions taken are always a reflection of the local geology and geographical setting. For instance, depletion of natural sand and gravel resources in Norway and Sweden have resulted in a move towards increased use of manufactured sand, either on its own or, more typically, in a blend with natural aggregates. Taxes have also been used to regulate material use in several European countries.

Flemish example: In 1993, the Flemish Government approved gradual reduction and ultimately termination of all gravel activities in the province of Limburg. Committees were formed to coordinate the accompanying measures, including restructuring, social aspects and research. This was financed by a gravel levy. A study, including a survey amongst concrete and asphalt companies, was carried out to assess the substitution possibilities. The general conclusion of this study is that, despite the planned decrease and the reduction of the market share, Limburg Meuse gravel and sand will continue to hold an important position within the Flemish and particularly Limburg economy with a local availability of approximately 2 to 3 million tons of Meuse gravel per year. The further decrease of the Limburg gravel quarrying will result in the forced switch to other aggregates for the companies with the consequent price increases. The substitution of Meuse gravel has already been in process for a few years but is primarily absorbed by the natural aggregates (limestone, sandstone and porphyry) from the Walloon Region. The qualitative construction sand will also become rarer together with the gravel. Countries in this area are "… striving in the long term to meet the need for construction raw materials in a socially acceptable way, in which the quantities produced, are defined by free market forces"[2].

2.3 Phase 2 Quarrying and production

2.3.1 Sub-activities

Once operative, the quarrying process incorporates a series of sub-activities to be considered also from an environmental point of view:

- *Extraction* of materials, which depending on the quarry type and location (hard rock, sand/gravel, land or sea) will involve drilling and blasting, hauling and/or dredging.
- *Handling and transport* of the materials internally within the plant by conveyors, loaders and trucks, and from the plant to the customer by truck, train or boat.
- *Production* of aggregate materials by means of the standard processes crushing, sorting/classifying and possibly washing.
- *Storing* the materials within the plant in silos or stock piles.
- *Waste depositing* of surplus sizes, most often surplus fines.

2.3.2 Key environmental issues

Potential impact of quarrying activities on external environment may be:

- Dust, noise and vibration
- Truck traffic near aggregate operations
- Visually and physically disturbed landscapes and habitats
- Affected surface and/or groundwater

Health issues for workers will first of all be connected with dust, and with the quartz content in the dust.

2.3.3 Issues of sustainability

- *The mass balance* will often be the key issue of sustainability in quarry production: A total mass balance should be aimed at, avoiding surplus materials like fines or over-size to be left in waste deposits.

- *Logistics and energy* consumption: The largest energy consumption within the aggregate industry is that related to transport. With a tendency of increased aggregate supply from far away sources in to the populated areas, this issue is becoming more and more a matter of concern. This tendency is partly due to constraints against quarrying, partly due to lack of relevant resources, and partly resulting from the need to have fewer and larger quarries for reasons of economy and legal handling.

2.3.4 Elements of BAT

Technology for preventing or reducing pollution in quarrying is mostly state-of-the-art, although often insufficiently applied.

- Potential *environmental impacts of extracting and transporting* aggregates should be identified in each case, and methods to avoid or minimize the impact should be determined. This could e.g. incorporate alternative means of transport.
- *Dust control* may be executed by careful location of equipment and stockpiles, dust collection on rigs, reducing the drop height of dusty materials, protection with telescopic chutes, skirts and/or covers, water fog spraying, covering of truck loads, keeping trucks clean (washing), water/chemical applications on roads and rubble piles, buffer zones, windbreaks, and finally by monitoring dust – and quartz – in breathed air (workers).

Mass balance can be improved by:

- Use of *novel crushing and sorting technology* that minimises surplus sizes. New and improved technologies are available to crush smaller aggregate sizes into cubical shape without excess fines generating. New dry classifying technologies are also available to make pre-designed grading curves for manufactured sand and fillers.
- By establishing *integrated plants* with on-site down-stream solutions, a lot of excess mass transport can be avoided. This will also result in higher consumption of all on-site produced aggregate sizes – thus minimising the need for depositing surplus sizes. Integrated solutions will also be a pre-requisite for a future possible development of under-ground solutions in densely populated areas.
- It is also essential that production be *balanced versus market*, to minimize the production of non-marketable sizes.

2.4 Phase 3 Use of aggregates in construction

2.4.1 Sub-activities

Aggregates are crucial ingredients in most construction activities and construction materials, the primary volumes being in road pavements, road bases and concrete. These are also the down-stream materials where the strictest requirements are set to properties and quality. Sub-activities in aggregate use will be performance analyses, quality control and materials proportioning.

2.4.2 Key environmental issues

All products must be in accordance with the essential requirements in the CPD, which means environmentally friendly products, with no negative health effects (e.g. asbestos, radon), nor polluting effect through leaching of chemicals to the environment. Besides, physical and chemical durability is also an environmental issue, through the effect for long term materials consumption and structural safety.

2.4.3 Issues of sustainability

A sustainable use of aggregates can be said to be a use that saves resources and minimizes waste deposits, and which also provides an end product with a minimum of energy consumption and a maximum of added value.

- Use of *recycled and/or secondary* materials – which are technically “good enough” – can in many cases serve this purpose, primarily when these resources are readily available without needing excess effort in production and delivery.
- Use of *crushed materials – manufactured aggregates* – as a replacement of increasingly scarce sand/gravel resources is another option, which in some cases can even improve materials properties.
- *Economically feasible* products that ad value in the short term and have a durability which prevents expensive restructuring / resurfacing on the long term will also be part of sustainability.

2.4.4 Elements of BAT

The first action to be taken is to investigate options and opportunities based on the local conditions and actual purpose for aggregate use. This includes to:

- Investigate the *performance of recycled* aggregate available to determine if and to which extent they can substitute natural aggregate.
- See if and how sand/gravel can be *replaced by available crushed materials*. Quantify the pros and cons regarding the proportioning and use of such materials. The conventional experience-based technologies have to be revised for application of crushed materials.

Aggregate requirements should be considered and discussed:

- Avoid (work against) *too strict and narrow requirements* to e.g. road materials in order to have a broader utilisation of sizes and less surplus materials.

Use new technology:

- Apply the newest standards and obtain *novel application and mixing technology* for crushed and recycled materials in product recipes, including the adaptation of chemical admixtures, depending on (and utilising the properties of) the aggregate/rock type available, and taking the specific end use into consideration.
- Implementation of *new test methods for characterisation of physical properties* of both aggregates and concrete, e.g. size, shape and density of aggregates and various rheological properties of concrete.
- Development and application of *new software* for modelling of packing and proportioning of mixes[3].
- General us of *advanced Quality Assurance system* with high degree for instrumented control[3].

  Refer to the attached table/flow-chart for BAT with manufactured aggregate concrete.

Experience shows that crushing and screening techniques depend on the local geological conditions, i.e. they must be tailored for each rock type to optimise the physical properties, such as grading, shape and surface texture. Similarly, use of manufactured sand requires revision of specifications to compensate for the difference in physical properties, as compared to aggregates from natural resources. This allows for a performance based approach[4].

2.5 Phase 4 Reclamation

2.5.1 Sub-activities

Key actions concerning reclamation of quarried areas are becoming still more vital in order to obtain the necessary permits for quarrying. This is an issue which will strongly depend on local conditions, needs and political priorities. Some relevant activities may be:

- Planning of reclamation before start-up of quarrying, as part of regulatory work (see item 1.1 above).
- Necessary action to investigate and preserve biological habitat.
- Restoration of the area, removal of pollutants, ensure cleanness.
- Establish new area for use, and shape the landscape, whether it be for an industrial, a residential or a recreational purpose.
- Establish vegetation zones, harmonized with the initial vegetation in the area.
- Secure the area in order to ensure physical safety for all public use.

2.5.2 Key environmental issues

Pollution and waste control will be crucial, avoiding all left-over of waste deposits, storage tanks and polluted soil. Control drainage and groundwater conditions.

2.5.3 Issues of sustainability

Long-term/permanent solutions should be established.
The creation of sustainable value for the society should be aimed at from the very first planning. A well planned quarrying is a first step to permanent solutions balancing industrial, environmental and societal priorities – and reflecting specific area needs.
Quarries will always be temporary; the business is to extract resources, not to possess land. After a given number of years the quarried land will be left over for restoration into alternative use.

2.5.4 Elements of BAT

Reclamation will call for interdisciplinary planning, decision-making and engineering.

- Provide essential data for implementing the reclamation.
- Obtain a broad ownership among stakeholders to the chosen solutions.
- Utilise a broad co-operation between disciplines and parties involved in order to ensure optimum solutions.

Table 1, an example:

BAT summary for making concrete with manufactured aggregate – Scandinavian conditions.

Process step		**Key factors**	**Actions**	**Comments**
Planning, concept		Situation as to resources		
		A need to utilise surplus sizes		
		Suitability of the rock type	Utilise rock properties	Strength, E- modulus, abrasion, density, chemical stability
			Compensate or avoid problems	Reactivity, weak/weathered particles, water requirement
Over all process		Mass balance	Flow-chart for mass balance and capacity	Adapt to market, Rock type → quality product in all sizes
		Environmental considerations	Dust control	Health, safety, neighbour relations
Crushing	Coarse sizes	Crushers adapted to rock type and end product. Degree of reduction, use of capacity	Choose optimum equipment	Good particle shape in coarse sizes is hardly a problem – well dimensioned cone crushers
	Inter-mediate sizes	Make a cubical 2-8 mm without excess 0-sizes and fines (as filler and coating). Any extra crushing will produce fines, 0-sizes high in fines will segregate, high energy consumption will cause a coating	Select and dimension crushers depending on rock; - rotopactors with low degree of reduction (cubisizing more than crushing) - new crushing concepts - impact crushers (e.g. in limestone)	Critical size range for particle shape – normal cone crushers will hardly contribute to cubicity
	0-sizes			Particle shape in smallest sizes determined by rock properties (size of minerals, crystal shape, texture).
Sorting	Coarse sizes	Traditional dry sieving		
	Inter-mediate sizes	Lower capacity with crushed than natural sand	”Flip-flow”- e.g. Trisomat	Even Norwegian natural sand gives less capacity than e.g. river sand
	Small sizes	Capacity, uniformity, keep the fines	Dry classifying (air) e.g. Buell-concept	Wet classifying less suitable in hard rock quarry
Concrete proportioning		Manufactured sand has different characteristics	Proportion as a unique material with unique properties	1 to 1 – compensation seldom successful (shape, grading)
		Chemical admixtures can be adapted to aggregate properties	Optimise fresh properties with admixtures and total grading	Dimensioning properties seldom a problem
		Filler size fraction – mineral type and grading	Use actively for stabilising / compacting	Part cement replacement in specific cases
		Required concrete type	Proportion for area of use	Dry-crete: Compaction Flow-crete: mobility and stability

2.6 Recycled, secondary and artificial aggregates

The problems with waste depositing from construction and demolition activities and the need for alternative mineral resources for new construction have been the two main drivers for research activities into recycled and alternative aggregates for some years. Actually, a lot more research has been going on in this part of the aggregate business than for natural/mineral aggregates. The current situation relating to recycled aggregates was discussed in the ECOserve Cluster 3 Baseline report a few years ago. Since then, some comprehensive research projects have been carried out, and several conferences have been dedicated to the theme. Important contributions to the development of this area can e.g. be found in

- Proceedings from the RILEM conference in Barcelona in 2004[5]
- The final report from the RILEM Committee 198-URM[6]
- Reports from the EU FP 5 project IRMA[7]
- Proceedings from the BCRA work-shop on recycling in road construction in Oslo in 2005[8]
- Reports, specifications and lectures/papers resulting from recent and on-going National projects and studies in several European countries. Useful guidance can e.g. be found in a series of lectures at the Bauhaus-University Weimar, Germany, e.g.[9] and in the reports from the Norwegian recycling project[10] that was concluded last year.

Briefly, the issue with developing and applying these materials is to **avoid a waste problem** and at the same time **cover a resource need** by converting surplus materials into valuable new materials. Whether the waste problem or the resource need is the main driving force in this development, will to a large degree depend on the local conditions in each specific case. Furthermore, the economic potentials of these solutions – often closely linked to public regulations and tax regimes – will be key conditions for making the environmentally friendly solutions sustainable.

2.6.1 C&DW

The main focus in this area has been on recycled aggregates from construction and demolition waste (C&DW). It has been estimated that roughly 180 million tons of C&DW is produced annually in Europe, which according to prognosis will double by 2010. A high proportion of this is concrete, bricks and tiles, which can be recycled to substitute virgin aggregates for several purposes. With a total aggregate consumption averaging 10 tons per capita, recycled C&DW should have a potential of replacing some 5-10 % of the virgin aggregates – the amount largely depending on the local conditions relating to e.g. population density, the kind of C&DW available, the degree of sorting and the production technology applied, availability of natural resources, conditions relating to public regulations, materials specifications/standards, transport logistics and the economic competitiveness.

Throughout Europe the amount of C&DW that is recovered for recycling varies from < 20 % to > 95 %[a]. Globally, there is a tendency observed that the recovery rate relates to the population density. We also see a dependency on raw materials availability and the conditions for disposal.

What strongly complicates the setting up of a European BAT in this area is also that composition of the C&DW varies strongly between the European countries, e.g. concrete (2→39 %), asphalt (6→21 %), masonry (42→92 %) and mixed rubble (2→11 %) – all according to Müller 2005. We therefore also see that technical specifications as to what is permitted for different applications vary a lot throughout Europe. Some countries have very detailed National application documents and well defined BAT, while others only work inside of the quite wide European standards.

Although a lot of research has been performed, and the processing as well as the use of the coarse fractions of C&DW in construction is mainly state-of-the-art technology, still a lot of development remains in order to utilise the finest size fractions of these materials. The broad practical implementation also awaits development of processes and equipment that can make quality assured C&DW production economically feasible also in scarcely populated areas.

2.6.2 Secondary aggregates

This is an in-homogeneous group of materials, for which focus and research so far has been scarce. It incorporates the surplus sizes from non-aggregate quarries (monumental stone, industrial minerals, mining) and from excavations and underground work.

The % non-used materials from monumental stone quarries e.g. can amount to 80-90 % in some cases, making the up-grading and re-use a huge economic and environmental potential. By developing technologies that can enable a more tolerant use of traditionally low-value materials (by processing/up-grading, alternative design, alternative application technology) we can provide sustainability also in reducing the need for transport.

2.6.3 Artificial aggregates

Artificial aggregates will have an impact on environment and sustainability in as far as waste and /or secondary/unused resources can be processed into more high value materials. This was e.g. the case with the Lytag LWA which was processed on the basis of fly ash, and it can also in a way be said to be the case for LWA based on the incineration of clay (which is normally in itself not considered an aggregate resource).

One alternative to an environmentally friendly, artificial aggregate is the potential fabrication of a LWA based on crusher fines. This technology has been adopted in Norway and used on selected rocks to produce light weight aggregates with very low density. Norwegian experience suggests that e.g. quarry surplus could be a raw material or part raw material for production of environmentally friendly artificial aggregates. This technology for production of water tight light weight aggregates with very high strength-

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[a] European Waste Catalogue for the categorisation of C&DW

density ratio was developed in Japan some 15 years ago, but has so far been associated with high production expenses. It is based on rock rich in SiO_2 (approx. 80%), Al_2O_3 and alkalis (resembling rhyolite), which is ground to a fine powder and then burned together with SiC (a foaming agent)[11].

3 CONCRETE PRODUCTION

3.1 Overview and scope

As it is described in Chapter 3 of the Baseline Report[1] the concrete industry has been handling sustainability issues throughout the last two decades. The development of a more sustainable concrete production has almost always been driven by economical reasons but it is expected that in the future environmental design will be treated alongside conventional design aspects such as safety, reliability and durability as it is introduced in a recent fib Bulletin[12]. Therefore, a broad description of BAT will serve as a tool to distribute technologies between European countries and widen the awareness of sustainable production methods.

Another indication, that environmental performance is to be included in the concrete specifications of the future, came at the BIBM 2005 congress[13] where it was presented how environmental production declarations should be an integrated part of CEN-standards for precast concrete products.

In the following sections various Best Available Technologies are discussed. However, since the local conditions (Section 1.2) are of great importance it is not attempted to rank the BAT's. Instead they should be considered a catalogue of ideas for inspiration and hopefully help to increase the level of the whole European concrete industry. Furthermore, it is recognised that BAT for sustainable concrete production is a very dynamic concept. Especially when it comes to production control, the development of systems for monitoring and supervising the production of concrete is improving rapidly, right from its constituent materials to the performance of the finished concrete product.

Table 3.1 Environmental aspects for concrete production.

	Aspects	**Refer to**
Constituent materials	Mix design, supplementary cementitious materials, by-products,	Section 3.2
Production of concrete	Mass balance, energy efficiency, zero-waste	Section 3.3
Structural design	-	Not treated here
Operation and maintenance	-	Not treated here
Demolition	Recycling	Section 3.3
Working environment	Self-compacting concrete	Section 3.4

One of the main benefits of concrete is the fact that it is accessible world-wide. The main constituents for concrete are available all around the globe as well as the production technologies. However, the concrete compositions all around Europe are different. They depend on which materials being locally available, regulations and most importantly on building traditions. Thus, concrete is very much a local material for local applications. Therefore, concrete is basically an environmentally-friendly material based on huge quantities of raw materials being produced close to its final use. Furthermore, concrete is normally designed to fit its purpose.

The aspects summarised in Table 3.1 are dealt with in the following sections. Note that only production of concrete is covered in this report. Structural design and operation of concrete structures are not included in the following.

Why is environmentally friendly concrete production interesting?

Sustainability is a very broad issue and every concrete producer would probably state that he is producing concrete in the most efficient and sustainable manner under the circumstances and conditions that are valid for him. So why should he bother to optimise mix design or recycle materials?

First of all it is cheaper to produce environmentally friendly concrete even though it may require investments in new equipment and new technology. Secondly it is expected that sustainability is going to be a competition parameter in the future market.

We have produced modern high quality concrete for several decades in Europe. However, when it comes to everyday concrete for less demanding applications (indoor, low grade) there is a need for a strong sustainable concept. These everyday concretes constitute the majority of all concrete being cast around the world but they are not very prestigious to consider for material researchers. It would impose a significant impact on the environmental profile of the construction industry if such a concept was developed and applied in the concrete plants.

Furthermore, a strong increase in the third-world construction markets is foreseen and export of know-how from Europe is believed to be beneficial for both the construction industry and the society.

3.2 Optimisation of mix design with respect to clinker content

Since one of the main environmental issues associated with concrete production is CO_2-emissions and the greenhouse effect, the amount of cement clinker is of paramount importance of the environmental performance of concrete.

Every concrete manufacturer is of course optimizing his concrete mix design with respect to cement content since this is typically the most expensive constituent. Therefore, an economical optimisation of concrete mix design very often also results in a sustainable one. However, if the optimisation is performed solely to reduce clinker content the result would be a very lean mix with hardly any cement at all. Therefore, optimum mix design is found where the performance criteria with respect to strength and durability (for the requested life time) are met with the lowest possible clinker content.

However, such an optimisation is very often overruled by other (short term) conditions:

- The contractor would like the performance of the concrete in its fresh state to meet his demands, which may influence the mix design. Also the transportation distance from concrete plant to the building site may influence the mix design.

- Most often the contractor would like the concrete to gain strength rapidly so that he can remove formwork and speed up the casting sequence. This typically asks for a higher clinker content especially under cold winter conditions.
- On the other hand hot weather concreting may demand for low clinker content.
- At the precast factory the casting sequence is even more important than at the building site since it affects the productivity of the precast plant directly. Therefore, precast concrete mix design is fine-tuned to the capacity of the precast plant in order to optimise the flow of products.

These items illustrate the typical dilemma between short- and long-term demands for sustainable concrete production.

One of the ways for a concrete producer to optimise mix design and minimise clinker consumption is to mix pure Portland cement with other mineral additions. When a concrete producer is adding new materials into his mix design he has to demonstrate that these materials do not cause problems for the concrete performance. It may be industrial residual materials that are meant to substitute cement or perhaps aggregates. Table 3.2 contains a flow chart giving an overview of all the possible properties that need to be investigated further before such a new material is implemented.

It is becoming more and more widespread to use blended cement to decrease the share of clinker in a mix design[14]. Thus, cement clinker is blended at the cement plant instead of the concrete plant (Section 3.2.1).

However, this trend also calls for more precise terminology when discussing the environmental footprint of concrete. It should be noted that cement is not just cement but rather binder and we must consider the clinker content per m^3 alongside the binder content. This causes problems in connection with the concrete standard EN 206-1 where all binders are simply termed cement (see following section).

Table 3.2 Guidance for application of new materials into concrete production. Source: www.greenconcrete.dk.

PRELIMINARY EVALUATION OF SUITABILITY. What constituent is to be substituted by the material?	BINDER	Cement	CHEMICAL AND MINERALOGICAL INVESTIGATION	Is the material hydraulic or inert?	PRE-TESTING OF ACTUAL CONCRETE MIX DESIGN INCLUDING CONTROL PARAMETERS, PRODUCTION AND PERFORMANCE PROPERTIES	PRODUCTION PROPERTIES	Slump	SUPPLEMENTARY TESTING (dependent on application and environmental exposure class)	MECHANICAL	Tensile strength
		Fly ash		Reactivity factor (k-factor)			Air content in fresh concrete			E-modulus
		Slag		Content of harmful substances that may impair the concrete quality and the environment			Separation			Stress-strain relationship
		Other		Content of new substances not normally found in concrete constituents			Strength development			Shrinkage/creep
							Heat development		Fire resistance	
	AGGREGATES	Fines (< 4 mm)	COMPARISON WITH EN 12068	Grading curve		PERFORMANCE PROPERTIES	w/c ratio chloride and alkali content		DURABILITY	Chloride diffusion
				Absorption			Air content in hardened concrete			Carbonation
		Coarse		Alkali reactivity			Frost/thaw testing			Alkali reactivity
				Chloride and alkali content			Target strength (grade)			Sulphate resistance
							Separation tendency			
	Mixing water		Use guidelines in EN 1008							

Regulations and application rules

The technical specifications for concrete production are given in EN 206-1 where 18 different exposure classes are defined to categorise the severity of the degrading mechanisms (moisture, frost, de-icing, saltwater, etc.). In Table 3.3 these classes are summarised. For each category the national application document (NAD) from each country may determine threshold values for cement content and w/c-ratio plus suitable cement types. The choice of values is governed by local conditions regarding expected lifetime, typical exposure severity and general experience with local materials. Therefore, the threshold values may differ significantly from country to country.

Table 3.3 Environmental exposure classes according to EN 206-1.

Severity index	**1**	**2**	**3**	**4**
Exposure class				
X0 (No risk of corrosion)	Unreinforced Very dry	-	-	-
XC (Carbonation induced corrosion)	Very dry Constantly wet	Rather wet (foundations)	Moderately wet (protected against rain)	Exposed directly to water, cyclic wet/dry
XF (Freeze/thaw, deicing)	Moderately wet and no de-icing (vertical faces)	Moderately wet with de-icing (vertical faces exposed to airborne de-icing)	Rather wet and no de-icing (horisontal faces)	Rather wet with de-icing (roads and bridge decks)
XA (Chemical environment in water and soil)	Weak	Moderate	Strong	-
XS (Sea water induced corrosion)	Air borne sea salt near coastal regions	Marine structures permanently submerged	Marine structures, cyclic wet/dry	-
XD (Chloride induced corrosion)	Air borne chlorides	Rather wet with chlorides (swimming baths)	Cyclic wet/dry with chlorides (parking decks, edge beams)	-

For the concrete manufacturers the NAD’s are important documents because they set up rules and limitations for their mix design. These rules may also influence the environmental footprint of the concrete as it is demonstrated in the following.

In ECOserve, Cluster 2, a mapping of these application rules has been carried out[14]. The NAD’s from various countries have been compiled and compared. This work has been carried out in close collaboration with CEN TC 104/SC1, which is responsible for EN 206-1.

It is clear from the comparison that the rules for concrete composition differ substantially from country to country. The durability aspect is dealt with mainly through the water-cement ratio and the cement type. For instance a buried concrete foundation, typically placed under exposure class XC2, should have max. w/c of 0.55 in Denmark, 0.6 in Norway and Sweden up to 0.75 in Germany (Table 3.4).

The wide interval of w/c-ratios for a given structure when comparing NAD's is due to the different opinions and philosophies that exist on durability and lifetime modelling across Europe. It is also a result of the 18 exposure classes being lumped together in simplified groups like it is done in Denmark and Norway instead of considering the whole range. It is obvious that such differences make it difficult to compare concrete structures across borders since the performance criteria differ.

Table 3.4 Examples of w/c-ratios for various exposure classes and NAD's.

w/c	**0.40**	**0.45**	**0.50**	**0.55**	**0.60**	**0.65**	**0.70**	**0.75**
Germany		XS3	XF4		BF			XC2 XC1
NL		XS3	XF4	BF	XC2	XC1		
Denmark	XF4 XS3			BF XC2				
Norway	XF4 XS3				BF XC2 XC1			
Austria		XF4		BF		XC2	XC1	
Italy		XF4 XS3	BF		XC2 XC1			

Notes:
XF4 = Bridge deck exposed to de-icing agents.
XS3 = Marine structure, splash zone.
BF = Building façade exposed to rain and frost/thaw (not exposed to air-borne seasalt)
XC2 = Foundation
XC1 = Very dry (indoor structures)

Beside restrictions on the w/c-ratio the NAD's also govern the minimum cement content for the various exposure classes. Figure 3.1 contains the relationship between maximum w/c and minimum cement content for a few countries. A certain environmental exposure class will give the required w/c ratio and then the curves indicate the required cement content. For Denmark and Sweden a special situation exist, namely the minimum cement content is placed at a very low level so that the concrete producers are free to suggest a mix design that meet the durability and strength requirements. However, this low level does not correspond to the actual cement contents found in Danish or Swedish concretes.

Summing up it can be stated that the national application rules, although they all relate to the same background document (EN 206-1), also impose a significant amount of local conditions regarding the possibilities of concrete production. This may of course be seen as an implication of the fact that concrete traditionally is not seen as import/export goods. In border regions however, this may indeed be a possibility especially with precast elements.

Furthermore, a wide range of cement types are found suitable depending on national experiences and availability of cements. In some countries such as Italy all cement types according to EN 197-1 are suitable whereas in Germany some of the blended cements are imposed with certain restrictions in certain exposure classes. In Scandinavia only the cement types being available are treated in the NAD. For more information on which cement types that are suitable for the various exposure classes refer to the Cluster 2 papers[14,15].

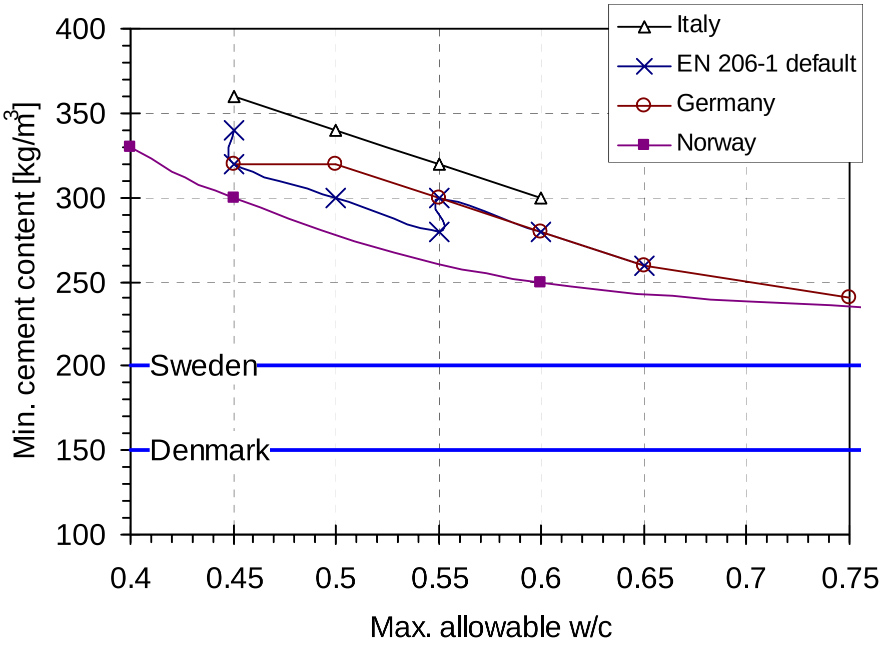

Figure 3.1 Examples of minimum cement content vs. maximum w/c ratio as governed by National Application Documents. Data taken from Cluster 2 report[14].
Note that in Denmark for infrastructure concrete (w/c < 0,45) the authorities require minimum cement contents just below the Norwegian line.

3.2.1 Reduction of clinker content

Cement types are regulated through EN 197-1, containing 27 different types. The most important being CEM I, II and III in terms of production figures (Figure 3.2 and 3.3). There are basically two ways of mixing Portland clinker and mineral additions in order to reduce the clinker content in the binder:

- At the cement plant by the cement producer obtaining blended cements (CEM II – CEM V). This method seems to be increasing especially in the central and southern part of Europe.
- At the concrete plant where CEM I is mixed with fly ash, silica fume, slag, etc. in the concrete mixer by the concrete manufacturer.

Actually other combinations also exist such as mixing of different cement types (e.g. CEM I and CEM III) or mixing of blended cement with mineral additions in the concrete mixer. The former being used in the Netherlands and the latter being allowed for in Sweden.

There can be stated several pro's and con's for the different methods but in the end it all comes down to the traditions and experiences in each country. One method puts the responsibility of the binder composition into the hands of the cement producer and the other gives more flexibility to the concrete producer to design the type of concrete to meet the specifications. Thus, both of the methods can be termed BAT when it comes to reducing the clinker amount in an efficient way.

The cement types II-V are further subdivided into A, B and C according to their decreasing Portland clinker content[b]:

- Portland cement: CEM I contains min. 95 % clinker plus 5 % minor additions such as gypsum.
- Portland composite cement: CEM II/B contains 65-79 % clinker and CEM II/A 80-94 % clinker.
- Blast furnace slag cement: CEM III/C contains 5-19 % clinker; CEM III/B contains 20-34 % and CEM III/A contains 35-64 % clinker.

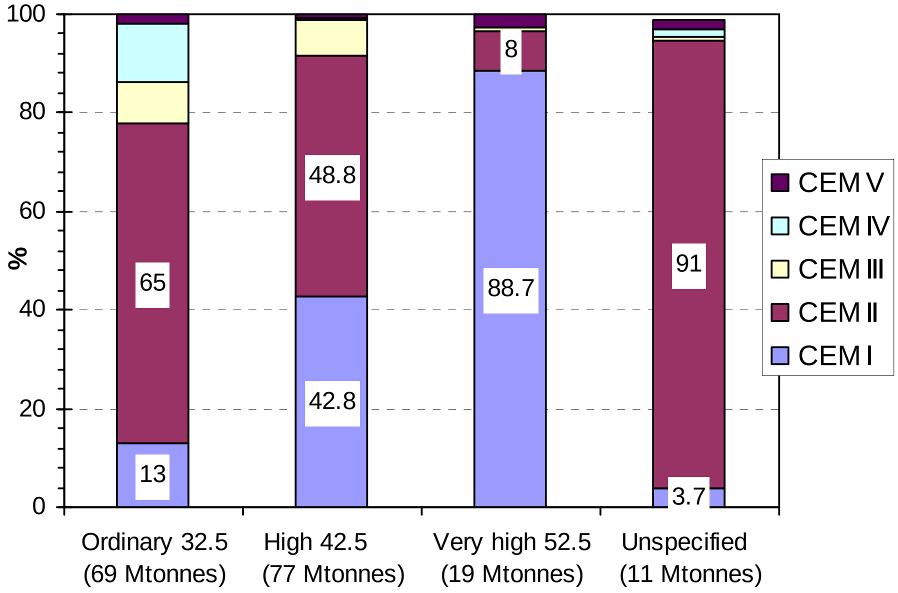

Figure 3.2 Cement production distributed on cement type and strength class. The numbers on the columns indicate the share in % of CEM I and CEM II within each strength class. Source: CEMBUREAU 2001 production figures.

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[b] Refer to EN 197-1 for details.

For the very high strength class CEM I dominates whereas for the ordinary and high strength class CEM II is increasing its share significantly (Figure 3.2 and 3.3). Unfortunately there is no subdivision of the production into sub-type /A, /B and /C. Figure 3.3 shows how CEM I is loosing its share to mainly CEM II while CEM III, CEM IV and CEM V still are rather modest production figures.

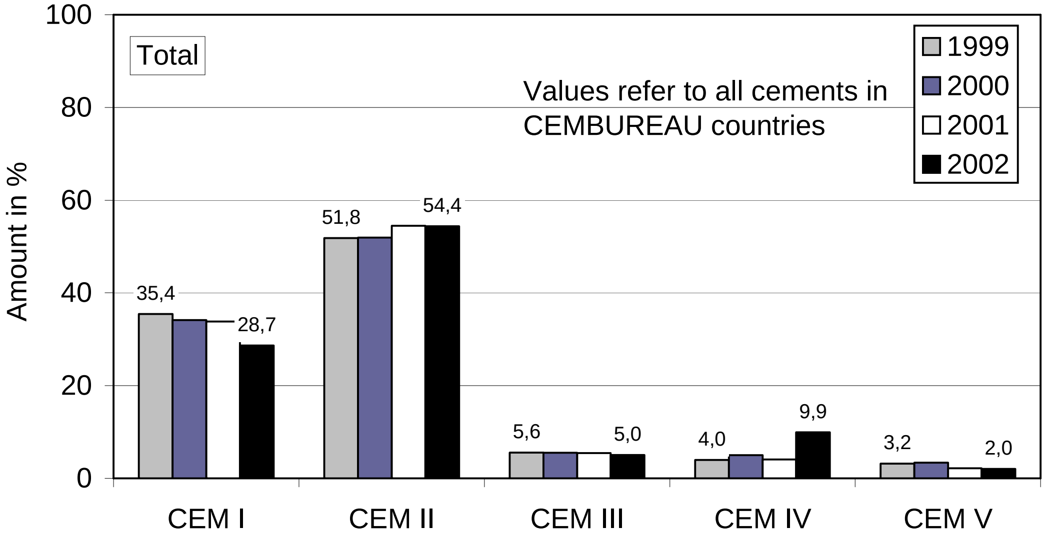

Figure 3.3 Development of cement production figures in CEMBUREAU member countries. Taken from Cluster 2[14].

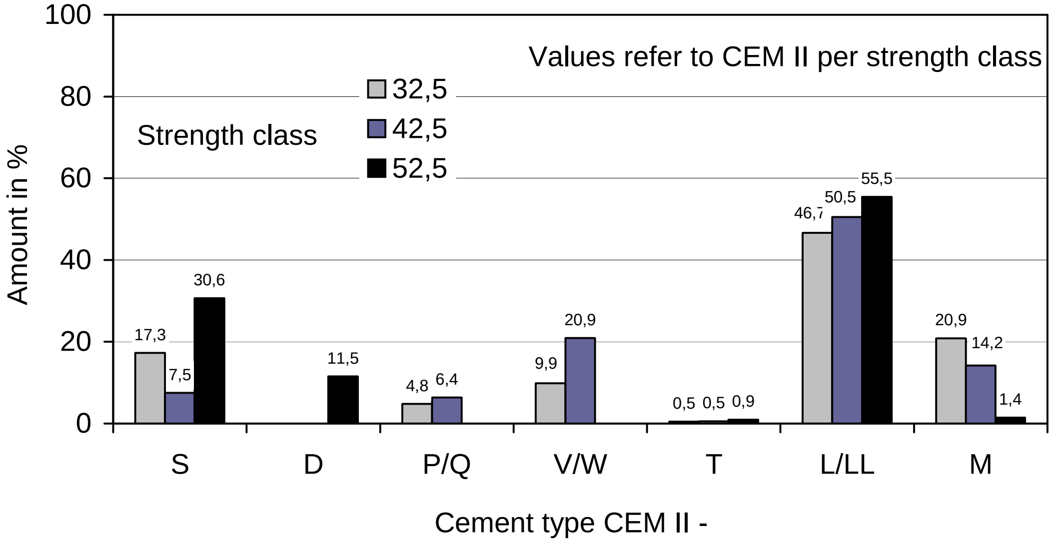

Figure 3.4 Production of CEM II cements divided in blending material. S = slag; D = silica fume; P/Q = pozzolana; V/W = fly ash; T = burnt shale; L/LL = limestone; M = combinations of the before-mentioned. Taken from Cluster 2[14].

In Figure 3.4 CEM II production figures are subdivided into type of blending material (slag, silica fume, pozzolana, fly ash, shale, limestone and mixed). It is clear that limestone is the most important blending material at present.

A rough calculation on the amount of Portland clinker per production unit cement shows that (1/3*950 + 1/2*800 + 1/6*650) kg/tonne = 800 kg clinker per tonne cement based on the distribution on cement types I, II and III given in Figure 3.3.

BAT for reducing clinker content

The choice of cement type is partly governed by the NAD's for EN 206-1. As it was mentioned previously the specifications given in the NAD's regarding suitable cement types differ significantly depending on exposure classes. However, there seems to be an agreement from most of the NAD's to allow use of CEM III/B, having 20-34 % clinker content by weight. On the other hand the production figures on CEM III do not support that this type is being used generally at present (Fig. 3.3).

The findings in ECOserve cluster 2[15] focus on slag, fly ash and limestone as mineral additions for blended cement. Furthermore, they consider mainly blended cement of type CEM II/B-M where the best performances obtained from fly ash (or slag) and limestone is combined. This cement type has clinker content down to 65 %. This cement type could be the basis for building components in moderate exposure classes (around C30), comprising a large share of the European concrete production.

If we assume that CEM III/B is the potential for minimum clinker content and combine this with the minimum cement contents in Fig. 3.1 we end up at a level around 50 kg clinker pr. m^3 concrete (see left-hand-side of Fig. 3.5). This applies for a concrete quality for building facades having w/c ratio somewhere between 0.5 and 0.6.

Figure 3.5 also illustrates the special situation with Denmark. In spite of the very low cement content the clinker content is still rather high compared with 50 kg/m^3. This is due to the fact that Denmark only allows for CEM II/A, having at least 80 % clinker content. However, for several reasons such low clinker contents are only possible in theory. The realistic scenario is depicted on the right-hand-side of Fig. 3.5.

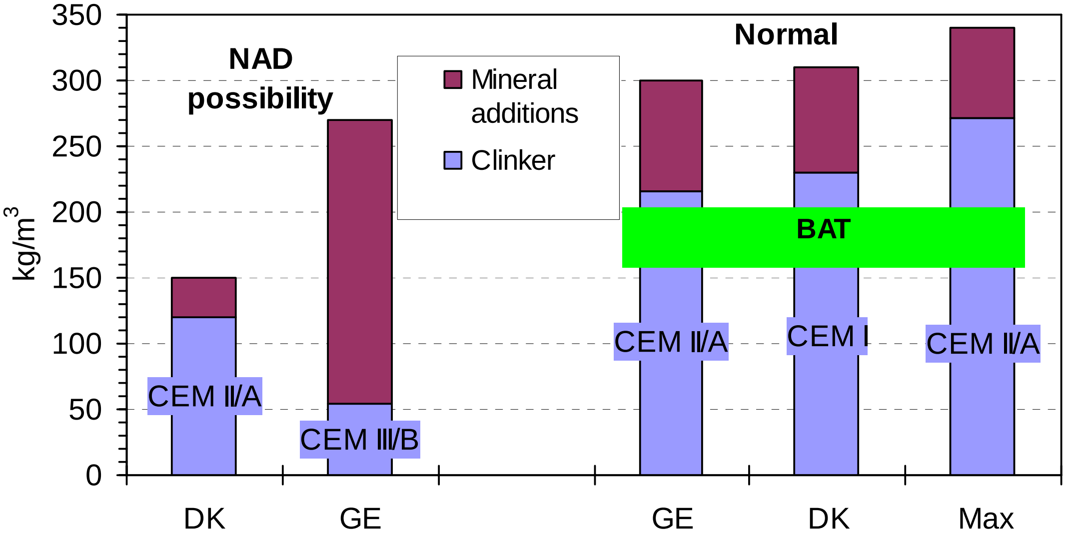

Figure 3.5 Cement content per m^3 concrete. For vertical building facades, exposure class XC4+XF1. Left-hand-side of diagram shows possibility for low clinker content according to NAD's. Right-hand-side of diagram shows normal situation based on realistic concrete mix designs and realistic cement types.

The right-hand-side of Fig. 3.5 illustrates realistic mix designs for the assumed application:

- The "GE"-column is considered to be typical for most of Europe (based on CEM II/A). This results in a clinker content of about 220 kg/m^3.
- The "DK"-column depicts the Danish situation which is mainly based on CEM I combined with fly ash (and sometimes micro silica) mixed at the concrete plant. The clinker result is slightly higher than the above.
- The "Max"-column depicts the maximum cement contents across Europe (based on CEM II/A). The clinker result is significantly higher than the above.

The examples clearly show that the EN 206-1 (with corresponding NAD's) does not limit the BAT when comparing the right-hand-side and the left-hand-side of Fig. 3.5.

Based on the conclusions in Cluster 2[15] with regard to CEM II/B-M it is estimated that for most European countries the BAT for clinker content makes it possible to produce concrete for moderate exposure classes with clinker contents below 200 kg/m^3. This is indicated by the green horizontal bar in Fig. 3.5.

Finally, it should be noted that there are other approaches to minimize the CO_2 footprint of concrete structures. A recent Nordic demonstration project[c] titled "CO2 uptake during

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[c] Partly financed by Nordic InnovationCentre, 2003-2005.

the concrete life cycle" has documented the effect of carbonation that takes place on all concrete surfaces exposed to the atmosphere. During carbonation concrete reabsorbs the CO_2 emitted during the calcination process in the cement kiln. After its service life the concrete structure is typically demolished and crushed to aggregates. By doing so the specific surface is multiplied and the carbonation process speeds up.

The results of the Nordic project[16] clearly show that this effect is significant and it should be included when considering the CO_2 emissions from concrete production (Fig. 3.6). The CO_2 flow for concrete is reversed compared with bio-materials such as timber. First CO_2 is emitted during production of cement and concrete but during operation and after demolition the calcinated CO_2 is reabsorbed. For the life-cycle of timber the CO_2 is absorbed during production and when the degradation of timber starts CO_2 is slowly emitted back into the atmosphere.

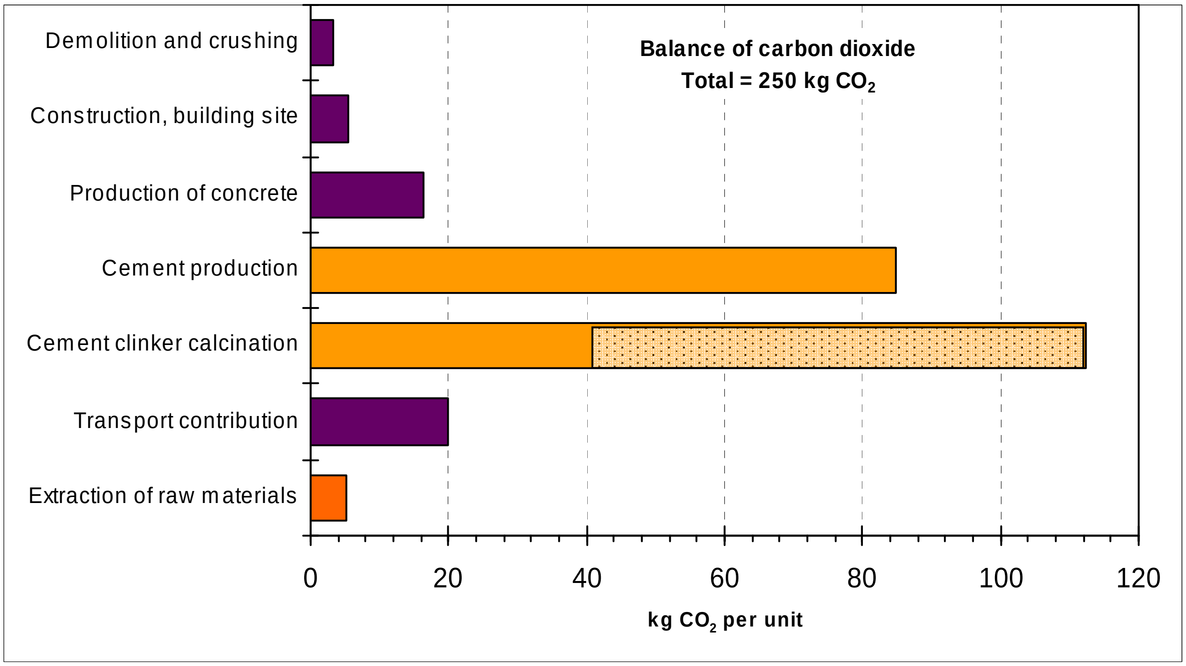

Figure 3.6 CO_2 emissions from various phases in the production. The functional unit is one m^3 concrete having 300 kg cementitious material (including 80 kg fly ash).
Orange columns are the embodied energy in the raw materials for concrete production.
Transportation from quarry to concrete plant and from plant to building site is combined in a single column.
The shaded part of the calcination column indicates the potential for uptake of CO_2.[16]
The background for LCA calculations on CO2 is described in reports[17][18] from task group 2.

3.3 BAT for production methods

During production of concrete (ready-mix or precast) the main sustainability aspects are related to mass balance, waste generation and energy consumption. It is obvious that all these aspects are also directly linked to the efficiency of the concrete plant and thereby to the production economy.

Another aspect that needs taking into account is the possibility to use local materials. This may include residual products from local industries, local aggregates from local quarries and crushed concrete from rejected batches and surplus production. All these options should be considered by the concrete producer together with an optimisation of mix design as described in the previous section 3.2.

Figure 3.6 shows the CO_2 footprint of concrete production including the embodied energy in its constituents. Again it is seen that the cement clinker are responsible for the largest portion by far and is often used as an indicator on its own.

The embodied energy of the cement amounts to 80 % of the total figure while the rest is taking place at the quarry, at the concrete plant, at the building site and at the demolition site. The importance of the transportation is also illustrated in Fig. 3.6 adding up to almost 10 % of the total figure.

Primary resources and mass balance

It is not possible to avoid waste generation under the production of concrete. However, the primary resources such as water, cement, aggregates, reinforcement and other building materials should be handled so that no excessive waste is generated. Furthermore, waste should be sorted and recycled to the widest extent, which also applies to other materials in a concrete plant.

Figure 3.7 shows how materials flow in the production of a concrete structure (primary raw materials to the left). The amount of waste generated from ready-mix concrete production is say 2 % while it is slightly higher at a precast plant for hollow core slabs due to saw-cutting of the finished products.

BAT for the surplus production, rejected batches and non-complying products, etc. is to recycle it back into construction. This typically includes crushing the concrete down to smaller fractions depending on its end-use. A certain level of sorting must be expected so that materials such as insulation, plastic and reinforcement is removed from the concrete. Typically the concrete manufacturer simply hires a mobile crushing unit when the amounts have reached a certain level. After crushing the materials may be sold of as secondary aggregates. It is also possible to transport the concrete waste to the crusher instead. The best solution depends on transport distances, waste amounts and the market for secondary aggregates.

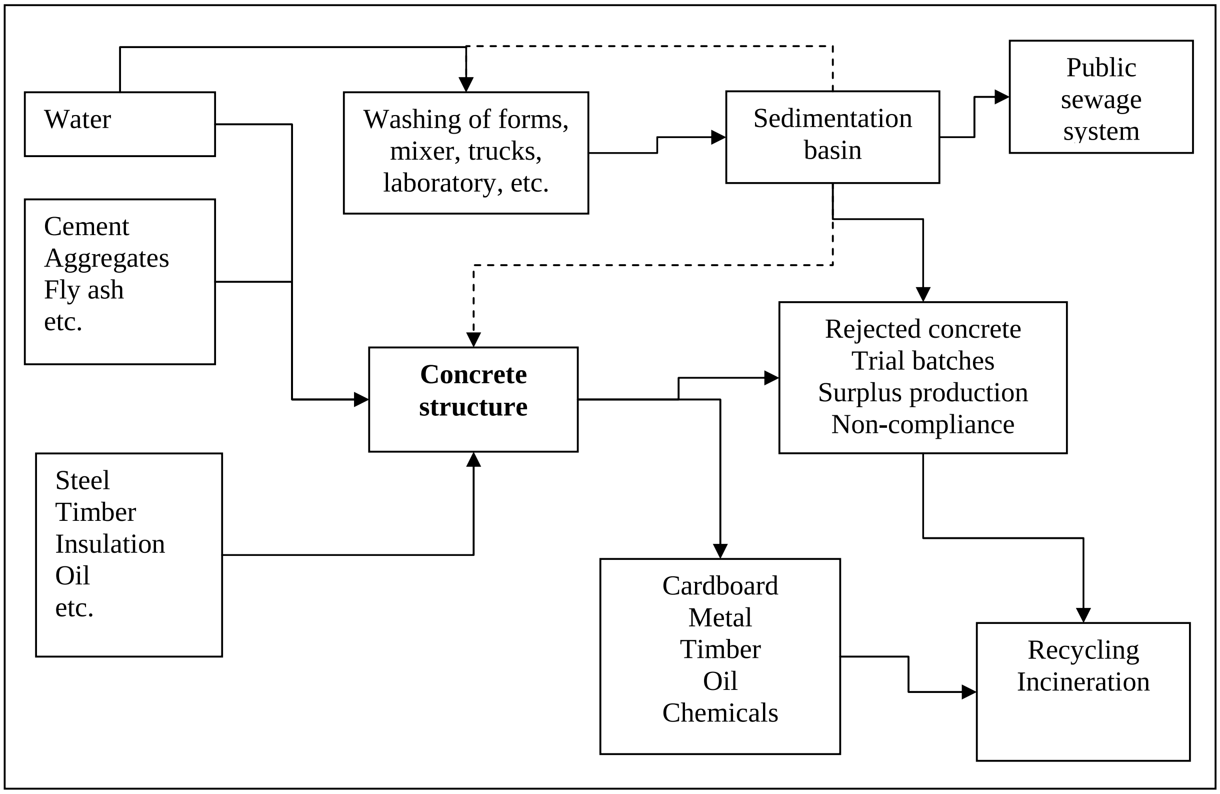

Figure 3.7 Flow chart of materials in concrete production.

With regard to water the concrete industry is a large consumer. The water demand for concrete mixing is depending on mix design and use of plasticising additives. However, a concrete plant also has relatively large water consumption for washing of mixer, conveyor belts, formwork, trucks and laboratory equipment.

The washing water goes to a sedimentation tank where the natural aggregates are reclaimed and the slurry sediments. Afterwards the water may be recycled back into the washing system or it may be added to the mixer. Processing plants for this type of water recycling are widely available and it is considered a well-known technology since the mid-1990ies. It is not considered a sustainable solution simply to discharge the waste water to a sewage system and furthermore, it requires chemical treatment due to its high alkalinity.

It is also possible to collect rain water from roof tops and paved areas and using it for washing and/or mixing water. Figure 3.8 shows water flows in an example taken from a British precast producer who has started recycling washing water. It is noted how the recycling save money for the producer in terms of a significant reduction in fresh water demand and no need for chemical treatment plant. Furthermore the society is benefited by means of less sewage to be processed at the water cleaning facility and reduced consumption of fresh drinking water.

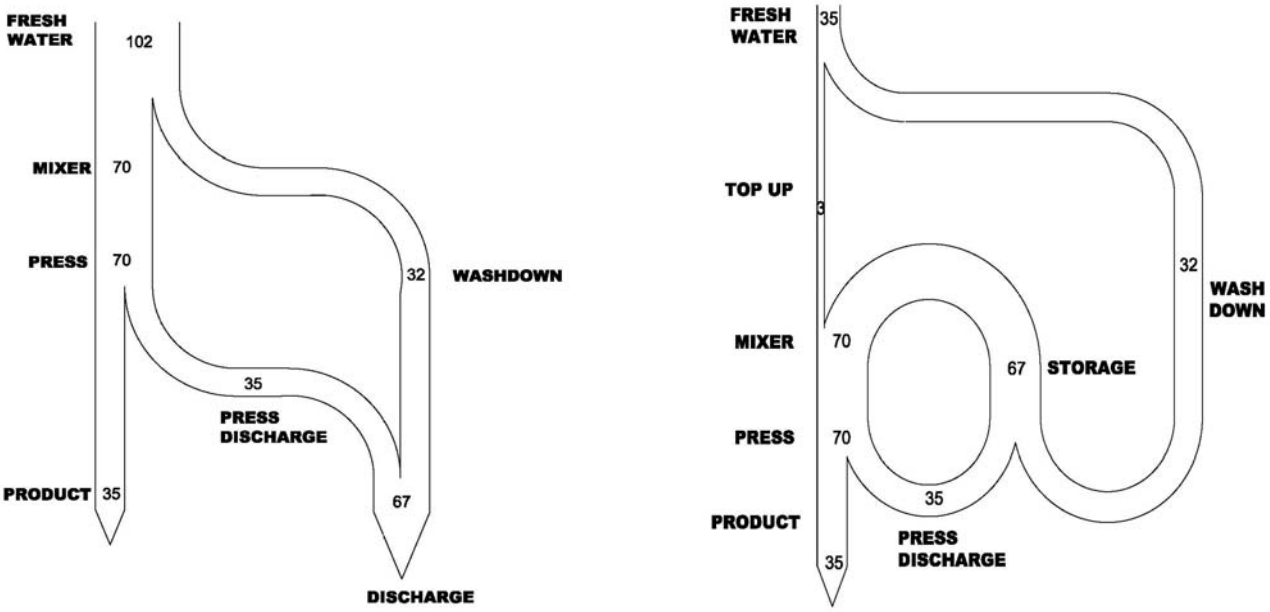

Figure 3.8 Water flow in precast production of concrete flags. Source: Marshalls plc.
Left: Original system with discharge to sewage system after an expensive chemical treatment.
Right: New system where washing water is recycled without any chemical treatment..

Recycling of demolition waste into concrete production

It is generally recognised that the technologies for recycling construction and demolition waste (C&DW) back into construction is already widely known and accepted. Thus, it is assumed that BAT on this subject is present and ready to be implemented. However the major hurdle is to establish the economical incentives in order to make recycling an option.

The amounts of C&DW were described in the Baseline Report[1] and it is estimated that about 500 kg/capita is generated in Europe annually. This figure is subject to a significant variation but the order of magnitude is correct. The amount of stony/concrete demolition rubble being recycled varies significantly across Europe and the figures are changing rapidly[12]. In Italy and Spain the amount of concrete recycling is about 10 %, in France it amounts to 20 %, in Germany about 80 % and in the Netherlands, Belgium and Denmark 90 % plus.

The principal applications of recycled concrete rubble are as follows:

1. Down-cycling it for road sub-base and back-fill material in connection with construction works. Since the quality and the homogeneity of the recycled concrete material varies significantly due to the presence of bitumen, bricks, gypsum, etc. its performance is mainly suitable for low-tech applications where performance is not top priority. Therefore, sub-base applications are the most interesting when it comes to recycling C&DW, which is considered BAT on the subject.

2. Recycling it into concrete as substitute for natural aggregates. This application is possible and the performance of the recycled aggregate concrete can be satisfactory when comparing with conventional concrete. However, due to the mortar and paste adhering to the recycled aggregates the water absorption increases and its mechanical performance diminishes compared with natural aggregates. Therefore, this type of application is more demanding for the quality of the recycled aggregates and it is generally not considered as BAT.

However, this picture may change if local conditions are in favour of using recycled aggregates for concrete production, being the case in parts of the Netherlands and Belgium due to shortage of natural materials.

Another important aspect that may change the picture is transportation. There are no sound environmental reasons for transporting C&DW excessive distances just in order to recycle it. C&DW should be crushed, processed and reused locally in order to make it a sustainable technology.

In the fib state-of-the-art[12], pp. 40-47, several references are given to technologies for processing concrete rubble in order to improve the mechanical performance of the recycled material. These technologies are mainly of Japanese origin and they include mechanical scrubbing of the rubble in order to remove the adhering paste. However, it is questionable whether these technologies are in fact environmentally friendly as they are energy consuming and costly. Again it depends on the local conditions and an overall life-cycle analysis.

Energy consumption

Figure 3.6 contains CO_2 emissions from production of ready-mix concrete. These emissions are all a result of energy consumption except the calcination part from cement clinker.

The impact of energy consumption for concrete production depends strongly on the energy sector in each country. Figure 3.6 is based on a European average[18]. Production of electricity differs from country to country and the amount of CO_2 emitted per produced kWh vary from below 0.1 kg in Sweden and France (due to a large share of nuclear energy and hydro power) to almost 1 kg in Estonia, Poland and Greece (due to coal fired plants). The European average is 0.5 kg CO_2/kWh. These differences make it impossible to suggest any specific BAT for concrete production. Thus, the effect of reducing the energy consumption will depend on the country of operation. However, it is obvious that reduced energy consumption is a goal for all producers for economic reasons.

A concrete plant is operated on a mix of energy forms based on electricity, diesel fuel and natural gas. These energy forms have different efficiencies and also different CO_2 emissions as stated above. It is estimated that ready-mix concrete production has an energy consumption from 100 MJ/m^3 up to several hundred[12], which again result in CO_2 emissions from a few kg/m^3 and upwards (Fig. 3.9). This is also strongly dependent on the climate on the production location since cold climate may require warm water and steam curing being energy demanding.

Basically the concrete manufacturer should carefully assess the available energy types in the production country and plan the plant equipment in accordance. It is not possible to give general solutions.

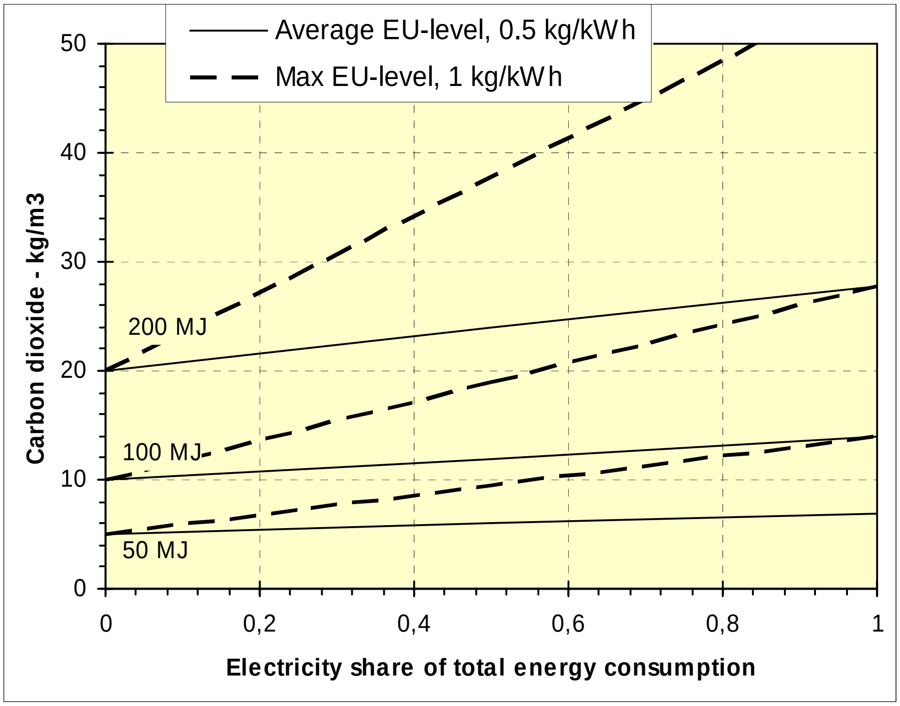

Figure 3.9 CO_2 emissions from ready-mix concrete production. The x-axis depicts the distribution of energy on electricity and mineral oil based fuels. The figures on the lines indicate the total energy consumption associated with the production of one m^3 of concrete. Transportation is not included.

Transportation of concrete as well as transportation of raw materials also demands energy. Again the CO_2 emissions depend on type from an ocean tanker being the most cost effective and small trucks being the most polluting means of transportation[18]. A diesel truck normally used for concrete and aggregates transport emits about 0.1 kg CO_2 per tonne·km while an ocean tanker emits less that one tenth of this. Transportation distances are of course important. It is estimated that normally one m^3 of ready-mix concrete requires say 100 tonne·km of transportation by truck (raw materials and concrete) but this is dependent on local conditions.

Noise and dust

Concrete production is by definition associated by a certain level of noise and dust. These matters are typically regulated by the authorities on the production location. However, there are several means to minimize noise and dust emissions[12], including:

- Restricting truck traffic to certain time windows.
- Noise insulation of mixer room and closed conveyor system for aggregates.
- Use of modern low-noise truck mixers.

- Hermetically closed circuits for cement and powders.
- Closed storage facilities for aggregates storage.

The necessary means depend strongly on the location of the plant and the noise level generated by the equipment. For instance a no-slump concrete producer of paving blocks requires a higher degree of noise insulation than a ready-mix plant. Noise and dust are both concerns for the working environment and also for the external environment depending on neighbours, etc.

3.4 Self-Compacting Concrete

Since self-compacting concrete (SCC) emerged on the scene in the late 1980ies in Japan it has been the subject to numerous investigations in order to adapt it to modern concrete production. At the same time the producers of additives have developed more and more sophisticated plasticizers and stabilisers tailor-made for the precast and the ready-mix industry.

SCC is defined as concrete which does not need any external energy to flow into its final position. Consolidation is ensured by means of gravity and the impact energy introduced when placing the concrete.

SCC has a long line of advantages as it was described in the Baseline Report. From the contractors point of view costly labour operations are avoided improving the efficiency of the building site. Furthermore, the concrete workers avoid poker vibration which is a huge benefit for their working environment. When vibration is omitted from casting operations the workers experience a less strenuous work with significantly less noise and vibration exposure.

It is expected that SCC is the concrete for the future since working environment is to be given more focus in the years to come. This is the reason why SCC has been given a separate section in the present BAT report. In the following the improvements of working environment are briefly described followed by a description of the technologies normally applied to produce SCC.

It should also be noted that SCC is believed to increase the durability relatively to vibrated concrete. This is due to the lack of damage to the internal structure, which is normally associated with vibration.

3.4.1 Working environment

For conventional concrete, noise and vibration are generated when the vibrators are being operated with noise levels sometimes exceeding 100 dB(A). Generally ear protection is needed when operating poker vibrators. The same can be said about precast plants where vibration is often applied through the formwork. According to European regulations, appropriate information must be provided to workers and personal ear protectors must be made available to them at workplaces where the daily noise exposure is likely to exceed 85 dB(A). Similarly, at workplaces where the daily exposure is likely to exceed 90 dB(A), the areas in question must be delimited and access to them must be restricted.

Provided that the background noise level is low, the use of SCC can lower the noise exposure on and around the construction site to approximately one tenth of the noise level produced when traditionally vibrated concrete is used[19] However, it should be noted that many other working processes beside vibrating concrete on a building site still makes ear protection mandatory. Especially for precast plants the noise level is reduced significantly when vibration is omitted during casting operations.

The reduction in noise levels will also improve the psychological working environment, improving internal communication at the site and providing less stressful surroundings, which again increases the health and safety for the workers. Here it should be kept in mind that improved health and safety pays back in terms of less sick leave and increased productivity.

Vibrations from handheld machines such as poker vibrators increase the risk of hand problems, especially problems such as poor blood circulation, the Raynand-Syndrome ("white fingers") and numbness. The use of SCC also prevents these problems and help reducing health problems for concrete workers.

Finally, SCC means fewer heavy lifts and improved ergonomics for the concrete workers. This is the case in particular when considering vertical casts (walls) where the vibration is taking place by lowering and lifting the poker vibrator in the formwork. The working positions during these operations are stressful to the back (bent over combined with torsion). For horizontal castings however, the benefits for the working environment are somewhat smaller than for vertical castings.

3.4.2 SCC technologies

Compared with conventional concrete (slump concrete) SCC needs to fulfil more sophisticated demands with regard to its rheology. Dependent on the casting method, the geometry of the formwork and the denseness of reinforcement the contractor need to specify the consistency of SCC. The criterion is that the concrete is able to flow sufficiently in order to fill the formwork completely, embedding reinforcement without any honeycombing or entrapped air.

The technical solution typically includes[20]

- lowering the yield stress with increased risk of separation between aggregates and paste. Lower yield stress means higher slump flow.
- adjustment of the viscosity to obtain a proper balance between fluidity and separation risk.

Determination of yield stress and viscosity is not a simple matter compared with a traditional slump test. Furthermore, since the aggregates grading curve and shape factor is also very important for the SCC rheological performance the composition of SCC is rather complicated requiring a high level of production control at the concrete plant. It is also realised that the workability of fresh SCC is more sensitive towards changes in weather conditions making it more difficult to cure properly compared with conventional concrete. These challenges may be the reason why SCC seems to have gained the strongest momentum within the precast industry where casting conditions are rather constant and the transport distance from the batching plant is low.

The mix design of SCC is different from conventional concrete. First of all due to the demands explained above SCC needs higher powder content and the use of effective additives, which will increase the material costs significantly (Fig. 3.10). The mix design of SCC is generally based on one of the three following principles:

- the powder-type SCC,
- the stabiliser-type SCC and
- the combination-type SCC.

The first principle is the original Japanese idea, where the stabilisation is based on an optimised grading curve from the fines to the coarse. This mix concept contains a comprehensive and systematic model for the composition of SCC. Depending on the raw materials, the powder content (cement, fly ash, limestone filler and fine fractions of the sand) lies approximately in a range of 500 to 650 kg/m^3. The powder-type principle is based on the acceptance that with a flow able mortar and a large viscosity simply by adding coarse aggregates and adjustment of the superplasticiser dosage a SCC is producible[21].

The stabiliser-type SCC is another type where the powder content lies approximately in a range of 350 to 500 kg/m^3. The absence of sedimentation stability due to less powder content, is compensated with inorganic and organic based stabilising additives (viscosity modifying agent). An optimisation of the grading curve is also strongly recommended.

The combination-type SCC has powder contents being an intermediate value of the powder- and the stabiliser-type. A possible advantage of using this type of SCC could be a reduction of the powder content regarding economical savings and to make the concrete less sensitive to variations of the raw materials (e.g. moisture content). The combination-type seems most promising since it gives the manufacturers more flexibility.

In Fig. 3.10 examples of the three principles are given in volume fractions of the constituent materials. It is clear that the paste volume is increased by means of adding fly ash. Note also that the balance between coarse and fine aggregates is significantly altered depending on the applied mix design principle.

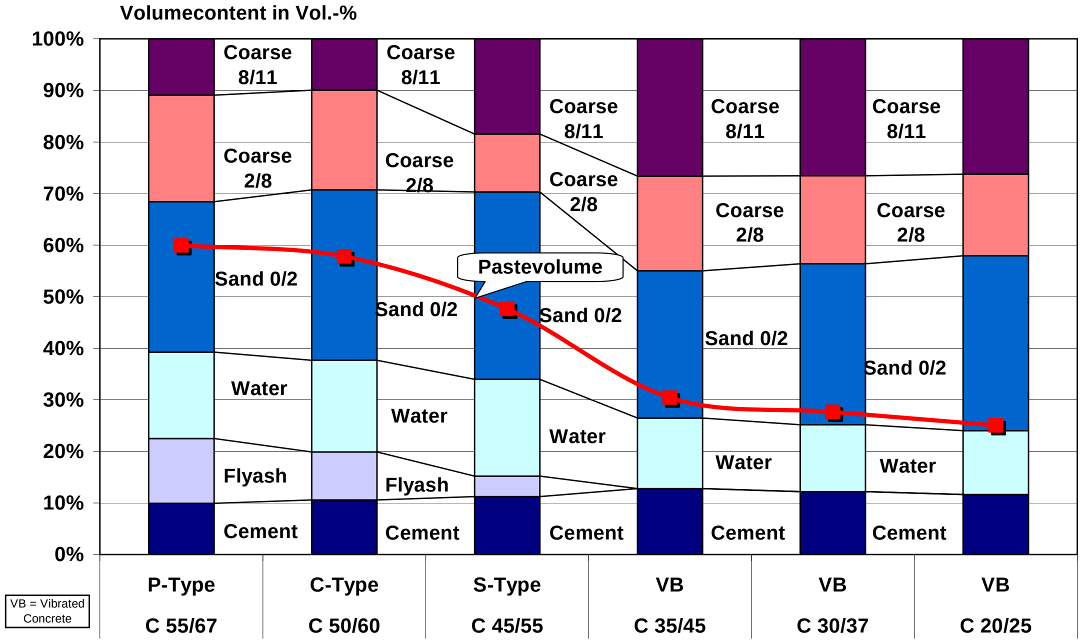

Figure 3.10 German mix designs[22] for conventional concrete and SCC applied in precast industry. P = powder type; S = stabilizer type and C = combination. The VB concretes are conventional. Cement type is CEM II/A-L 42,5R.

BAT for SCC

Since SCC mix design involves many different principles depending on the local materials and traditions it is not possible to determine whether one principle is better than others. Another important factor in SCC production is the strong position of the suppliers of chemical admixtures. In many cases the suppliers perform research and development and also assist the concrete producers in mix design. Furthermore, the choice of materials is very much dependent on the availability of suitable materials (fly ash, limestone, stone dust, etc.). It should be noted that besides the special specification of rheology SCC is also subject to considerations concerning heat of hydration, strength development, curing, etc.

From an environmental point of view the powder combination of SCC needs to be considered carefully so that the increased paste content does not mean increased cement clinker content. Thus, by improving the working environment we should not impair the impact on the external environment. However, SCC also mans new applications for industrial residual products that may be used as filler in SCC. The increased need for fines could increase the demand for surplus materials generated in the aggregate industry or it could mean use of ash products from various incineration processes. Finally, SCC means a higher level of mix design optimisation and better production control, which again may influence conventional concrete production in a positive way.

The most obvious new materials (besides fly ash, slag, limestone, etc.) to consider as filler material for SCC are:

- sewage sludge incinerator fly ash
- municipal waste incinerator fly ash
- Natural fines surplus from washing of natural aggregates
- stone dust from crushing of rock
- cement kiln dust

Table 3.5 Examples of SCC mix designs for precast structural elements. Source: SCC-konsortiet[d].

Constituent	SCC precast	SCC precast	SCC precast
CEM II/A-LL 52,5 kg/m^3	397	357	357
Fine sand kg/m^3	0	60	0
Cement kiln dust kg/m^3	0	0	35
Water kg/m^3	149	149	149
W/C	0.38	0.41	0.41
Slump flow mm	600-650	650	650
Fresh air vol-%	5.9	5.0	5.2
1 day strength MPa	> 28	-	32

Table 3.5 shows examples from Danish precast industry where such new materials are applied instead of cement without lowering the performance of the concrete. All mix designs are based on superplasticizer and no stabilizer.

In a similar manner Table 3.6 contains examples of ready-mix concrete designs where the filler content is increased with fly ash and or cement. However, it is seen that in order to obtain high strength classes and low W/C ratios the cement content is increased significantly.

Table 3.6 Examples of SCC mix designs for ready-mix industry. Source: SCC-konsortiet.

Constituent	Conventional	SCC	Conventional	SCC precast
Strength class	C25/30	C25/30	C35/45	C35/45
CEM I 52,5 kg/m^3	212	198	290	359
Fly ash kg/m^3	53	132	52	63
Water kg/m^3	143	147	132	157
W/C (incl. reactivity factor 0.5 on fly ash)	0.60	0.56	0.42	0.40
Paste vol-%	23.3	26.7	26.5	29.8

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[d] Danish R&D project, 2002-2007. www.SCC-konsortiet.dk

Regulations and standards

One of the reasons for the rather slow implementation of SCC is that the technology has been and still is under development around Europe. There are several reasons for that:

- The task of producing SCC which is stable and fluid is being developed according to the constituent materials available at the place of production. Furthermore, it is rather troublesome to obtain a SCC which is robust towards the production conditions from the mixer to its final position in a structure.

- Consultants and building owners are reluctant to specify SCC since the concrete standard EN 206-1 does not cover non-vibrated concrete. Furthermore, new test methods are under development in order to categorise SCC in a plausible manner.

The former is mainly associated with technical problems that are being dealt with in several national R&D studies around Europe. The latter however, is being dealt with by the European Project Group[e] who has published a set of guidelines for the use of SCC[23]. These guidelines form a pre-normative document that is assumed to be adopted into EN 206-1 in some form.

These guidelines consider specifications for use of SCC in both precast and site concrete, introducing new classes to specify its flowability in the fresh state:

- slump-flow
- viscosity
- passing ability (blocking)
- segregation resistance

For each class a suitable test method is proposed together with advice on what class to choose for a given application.

The introduction of a SCC-specification will undoubtedly help SCC to be more widely used especially in the ready-mix industry where the development is going rather slow (Fig. 3.11).

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[e] Consisting of BIBM, CEMBUREAU, ERMCO, EFCA and EFNARC

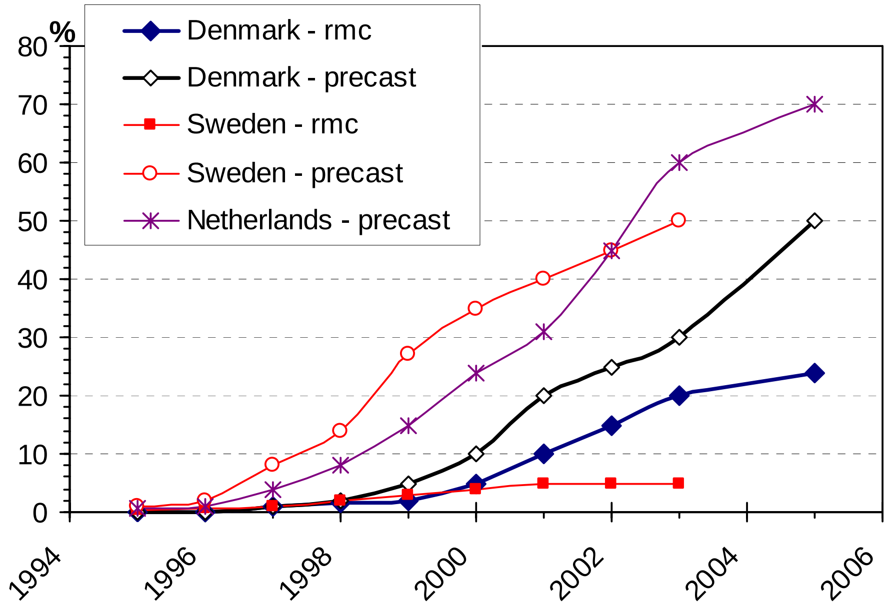

Figure 3.11 SCC share of concrete production (rmc = ready-mix concrete).
Note that precast production excludes concrete products (paving blocks, roof tiles, pipes, etc.) typically being cast with no-slump concrete. The precast figure for Denmark is approaching its potential of about 60 %, the remaining 40 % of the production is extruded or no-slump concrete. For the Netherlands precast industry the potential also seems to have been reached[f24].

3.5 Check list / guidelines for-concrete manufacturers

From the previous sections it is obvious that each concrete producer has many considerations to make and many decisions to take if he wishes to produce concrete in a sustainable manner. A specific guideline is impossible to apply due to the vast number of possibilities with regard to available materials, concrete plant technologies and market mechanisms.

It can be stated however, that it is not the regulations from concrete standardisation that set the limit for environmentally friendly concrete production. EN 206-1 and corresponding national application rules are quite liberal when it comes to reducing the CO_2-footprint of concrete.

A check list has been prepared below in order to assist the concrete producer in choosing the correct technologies for environmentally friendly production. If you cannot answer yes to the questions in the left-hand column there may be room for improvement and further considerations.

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[f] According to personal communication with Dr. H.W. Bennenk,

Note that the last two rows contain considerations that are not always under the concrete producer's control. It is rather a matter to be taken into account by the designer or the contractor. However, for precast production the concrete producer is also often both designer and contractor at the same time.

There is no correct way of producing environmentally friendly concrete. It is a complicated evaluation that takes into account the full life cycle, including numerous parameters that are often not controlled by the concrete producer and furthermore, non-environmental issues are often overruling the decision. However, if a concrete manufacturer is going through the check list then he is forced to address the environmental issues and to consider the need for changes. This will in most cases be a process that leads to more environmental consciousness in the industry.

Environmental issues to be considered by the concrete producer	**Environmental effects**
Are locally available aggregates being utilised in the widest possible extent?	Minimisation of transportation.
Are your mix designs optimised with respect to packing of aggregates? Do your mix designs contain supplementary cementitious materials as substitution of cement clinker? If yes – are these materials residual products from other industries?	Reduced consumption of cement clinker and reduced CO_2 emissions. Reduced need for depositing of industrial residual products such as ash and slag and reduced use of natural resources.
Is your plant equipment up-to-date and well-maintained? Do you have a procedure for energy awareness and resource consumption amongst the employees?	Minimum energy consumption and reduced waste generation.
Are the proper actions taken to minimize noise and dust?	Improved working environment and external environment.
Do you use vegetable based release agents to the widest extent? Also vegetable based hydraulic oils?	Bio-degradable materials and reduced risk of hydrocarbons in concrete slurry.
Do you reuse washing water after the sedimentation tank? Either as mixing water or washing water. Do you collect rain water to use in the production?	Minimised consumption of natural resources and reduced waste generation.
Is concrete slurry from the sedimentation tank being recycled? Do you reclaim aggregates from fresh concrete? (surplus production, rejected batches) Do you crush and recycle hardened concrete waste? (in other constructions or back into concrete)	Reduced consumption of natural aggregates and reduced need for waste depositing.
Do you collect and sort other waste for proper recycling? (paper, plastic, metal, mineral oil, chemicals, etc.)	Reduced need for depositing and reduced consumption of resources.
Is the working environment benefited from the chosen concrete solution? (SCC)	Better conditions for the concrete workers both at precast factories and on building sites.
Is the concrete optimised with respect to its purpose? (strength, durability, structural design) Is the concrete hydration fully utilised with respect to drying of surplus moisture before finishing works and also with respect to proper strength development?	General optimisation of the concrete design to fit its purpose in the final building or civil structure.

4 RESEARCH NEEDS

Being mature industries with a civilisation-long history, these industries will hardly be expected to undertake major leaps in development. Having a great environmental and societal influence, however, these sectors will need to continuously consider new technological options, and any improvement or development will immediately have significant impact on society.

Probably the most urgent needs in the near future will be to comply with increasing requirements and expectations concerning sustainability and environmental profile. Such aspects include e.g. the consumption of resources, emissions and pollution, waste generation, use of energy and public health issues. It is a major challenge to meet these requirements while maintaining a profitable production of some of the most needed and consumed materials in the modern society. Furthermore, it is a challenge for the industry to brand concrete as a sustainable building material in the public opinion. It is expected that within a few years, the construction industry is going to comply with environmental performance criteria as well as other performance based criteria on durability and strength, etc. Relevant standards on these issues are currently under construction.

A number of specific research topics were summarised in the Baseline-report under the four headings: (i) concept development, (ii) production technology, (iii) basic materials knowledge, (iv) application technology of materials.

For the aggregate industry:

- Concepts for competitive use of manufactured aggregates
- Technology to benefit from specific rock properties
- Utilisation of secondary aggregates /marginal resources
- Concepts to constantly obtain mass balance
- Concepts to use local materials
- Integrated plant concepts
- More economically feasible subsurface quarrying, combined with establishing underground space

For the concrete industry:

- Further use of supplementary cementitious materials for the everyday concrete production with moderate environmental exposure.
- More information on the potential for CO_2 uptake of concrete through carbonation.
- Better assessment of possible leaching problems associated with carbonated crushed concrete rubble.
- Improved methods to produce environmentally friendly self-compacting concrete.
- More focus on performance based specifications rather than prescriptive design.
- Utilisation of concrete in buildings not just as a load carrying material but also as a thermal storage medium.

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